Rare Process Frontier

Stefania Gori
UC Santa Cruz

Snowmass Community Planning Meeting,
127. Searches for dark sectors
October 6, 2020

Focus of RF6

Topical conveners: Stefania Gori (UCSC), Mike Williams (MIT)
sgori@ucsc.edu **mwill@mit.edu**

Production and detection of (relativistic) dark sector particles
(Dark Matter (DM), mediators, DM excited states, …)
at accelerator experiments

Main focus: high-intensity accelerator experiments

Collaboration with high energy, neutrino, and accelerator frontiers

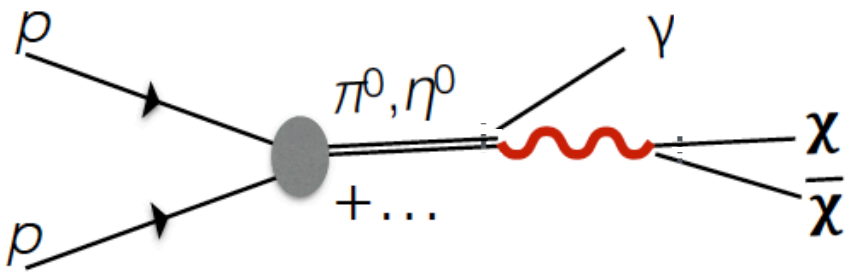
We have received 54 LOIs in total
https://snowmass21.org/rare/dark

see our townhall discussion last Friday: https://indico.fnal.gov/event/45713/timetable/#20201002

Many Faces of Dark Sectors

Organization of RF6

People & facilities naturally organize by initial-state…



from N.Toro, EF/RF/AF Cross-frontier dark sector meeting, July 16, 2021

1. Theory of dark sectors
2. e^+e^- experiments
3. Fixed-target experiments
4. Kaon factories
5. Low masses @ EF facilities
6. Neutrino experiments
7. Other opportunities

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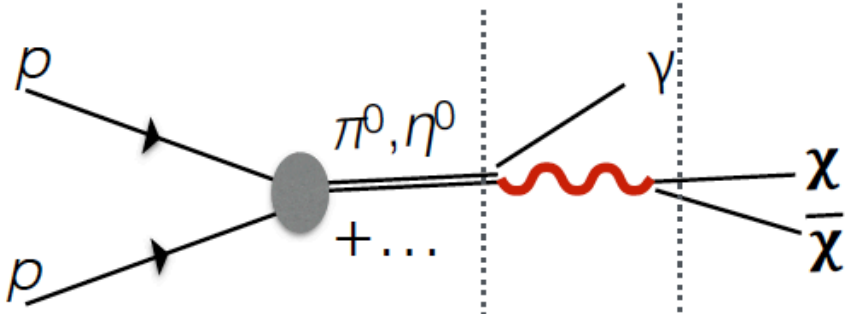

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People & facilities naturally organize by **initial-state**…

x Theories naturally organize by **intermediate-state** "portals"

x Science case naturally aligned with whether **final-state** is SM, non-SM, or mixed

1. Theory of dark sectors
2. e^+e^- experiments
3. Fixed-target experiments
4. Kaon factories
5. Low masses @ EF facilities
6. Neutrino experiments
7. Other opportunities

All three axes are important, both in mapping the physics and understanding detector design and capabilities.

Final states to look for

1. Invisible, non-SM

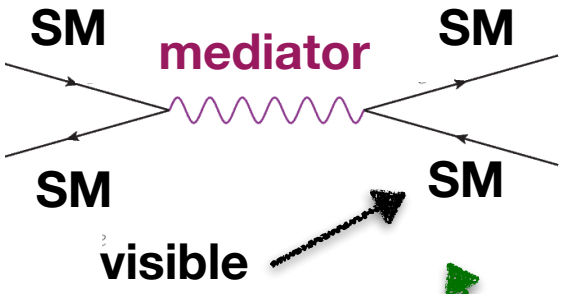
Dark Matter production

Producing stable particles that could be (all or part of) Dark Matter

2. Visible, SM

Production of portal-mediators that decay to SM particles

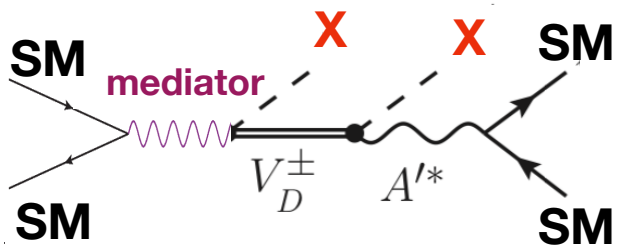
Systematically exploring the portal coupling to SM particles



3. Mixed visible-invisible

Production of "rich" dark sectors

Testing the structure of the dark sector



talk by Gordan Krnjaic in 108

(Accelerator Probes of Light Dark Matter)

Main topic of this talk

Possible benchmark models

Preliminary

Benchmarks in Final State x Portal Organization

	DM Production	Mediator Decay Via Portal	Structure of Dark Sector
Vector	m_χ vs. y [$m_{A'}/m_\chi$=3,α_D=.5] **$m_{A'}$ vs. y** [α_D=0.5, 3 m_χ values] m_χ vs.α_D [$m_{A'}/m_\chi$=3, y=y_{to}] m_χ vs. $m_{A'}$ [α_D=0.5, y=y_{to}] *Millicharge m vs. q* **1.**	$m_{A'}$ vs. ϵ [decay-mode agnostic] ***$m_{A'}$ vs. ϵ [decays]*** **2.**	**iDM m_χ vs. y** [$m_{A'}/m_\chi$=3,α_D=.5] **(anom connection)** **SIMP-motivated cascades [slices TBD]** $U(1)_{B-L\,/\,\mu-\tau\,/\,B-3\tau}$ (DM or SM decays) **3.**
Scalar	m_χ vs. sinθ [λ=0, fix m_S/m_χ, g_D] (thermal target excluded 1512.04119, should still include) Note secluded DM relevance of S→SM of mediator searches	*m_S vs. sinθ* [λ=0] *m_S vs. sinθ* [λ=s.t. Br(H→ϕϕ ~10^{-2})]?	Dark Higgssstrahlung (w/vector) scalar SIMP models? Leptophilic/leptophobic dark Higgs?
Neutrino	e/μ/τ a la1709.07001?	*m_N vs. U_e* *m_N vs. U_μ* *m_N vs. U_τ* Think more about reasoanble flavor structures	Sterile neutrinos with new forces?
ALP	m_χ vs. fq/l [λ=0, fix m_a/m_χ, g_D] (thermal target excluded) What about f_γ, f_G?	*m_a vs. f_γ* *m_a vs. f_G* *m_a vs. f_q=f_l* (separate?) Think more about reasoanble coupling relations including $f_{W/Z}$	FV axion couplings

\+ Neutron portal? Hidden valleys (or are these out-of-scope?)? See e.g. 2003.02270

Bold = BRN benchmark, *italic=PBC benchmark.* others are new suggestions. Underline=CV benchmarks that were not used in BRN

Ongoing call for new benchmarks & theory targets:

https://docs.google.com/forms/d/e/1FAIpQLSeNWJ7oVvjl6UoRS39ZHwpji_IN-hbJaI-d-JO9QRYavBiOtA/viewform

1.

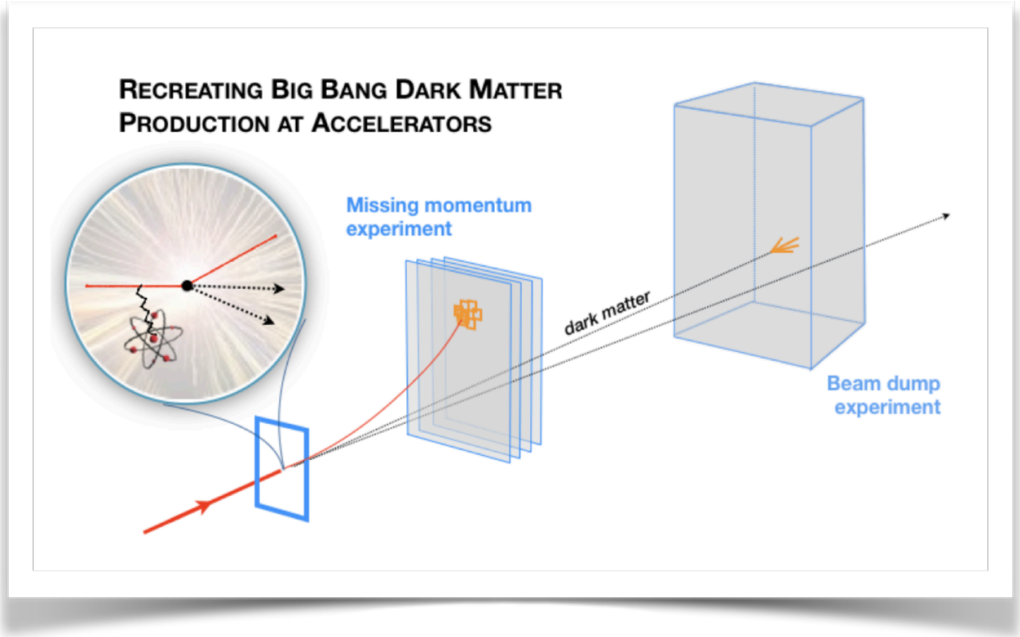
Invisible, non-SM

See Gordan Krnjaic talk in 108

Dark Matter particles can be produced at
* colliding beam experiments
* fixed target experiments

They can be detected
in form of
* missing energy (LHC(b), BelleII, …)
* missing momentum (NA64, LDMX, …)
* missing mass (JLAB e^+, …)
* through scattering with detectors (BDX, MiniBooNE, Coherent, …)

Dark Matter New Initiatives BRN report



https://science.osti.gov/-/media/hep/pdf/Reports/Dark_Matter_New_Initiatives_rpt.pdf

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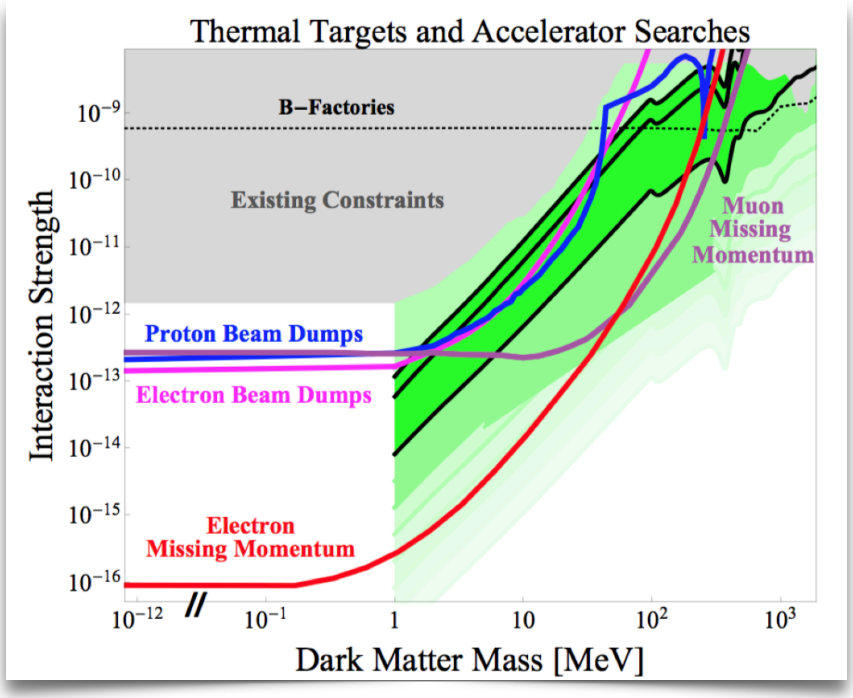

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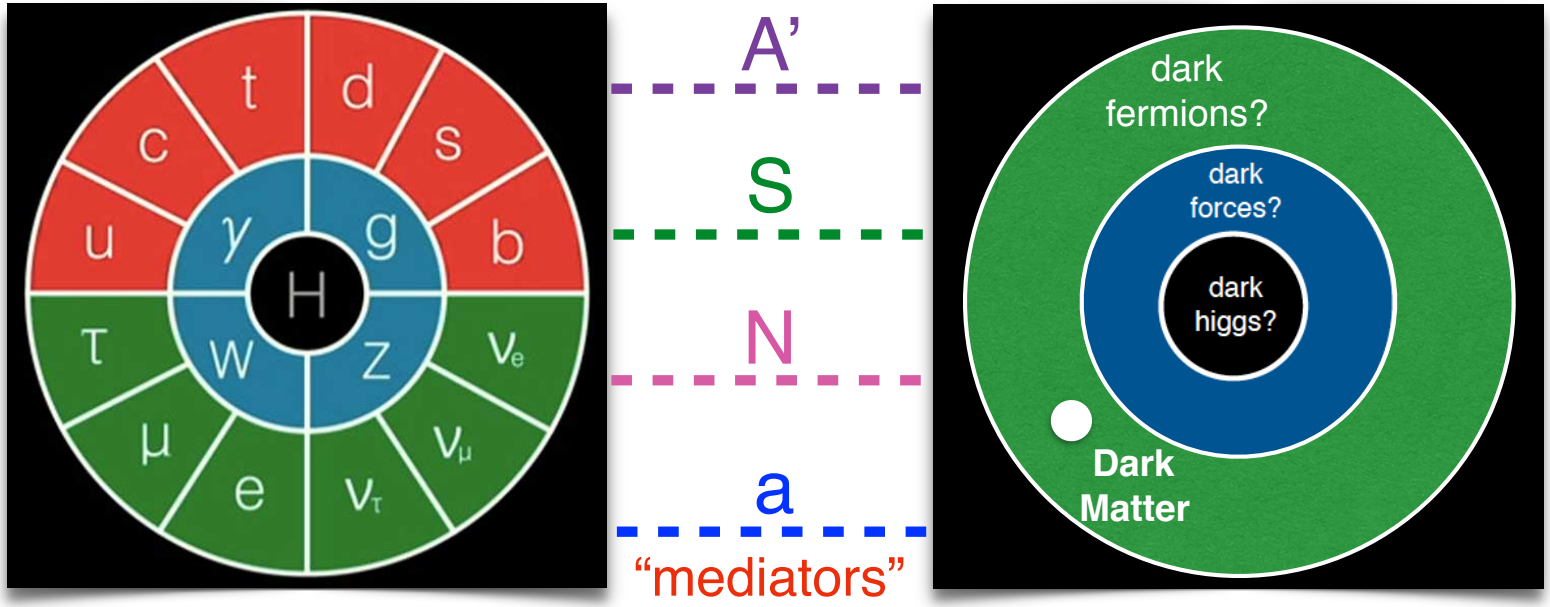
2.

Visible, SM.

Probing the mediator-SM coupling



Only a few interactions exist that are allowed by Standard Model symmetries:

"mediators"	"portal interactions"
Dark photon	$\epsilon B^{\mu\nu} A'_{\mu\nu}$
Higgs	$\kappa \lvert H \rvert^2 \lvert S \rvert^2$
Neutrino	$y H L N$
Axion	$g_{a\gamma} a \tilde{F}_{\mu\nu} F^{\mu\nu}$

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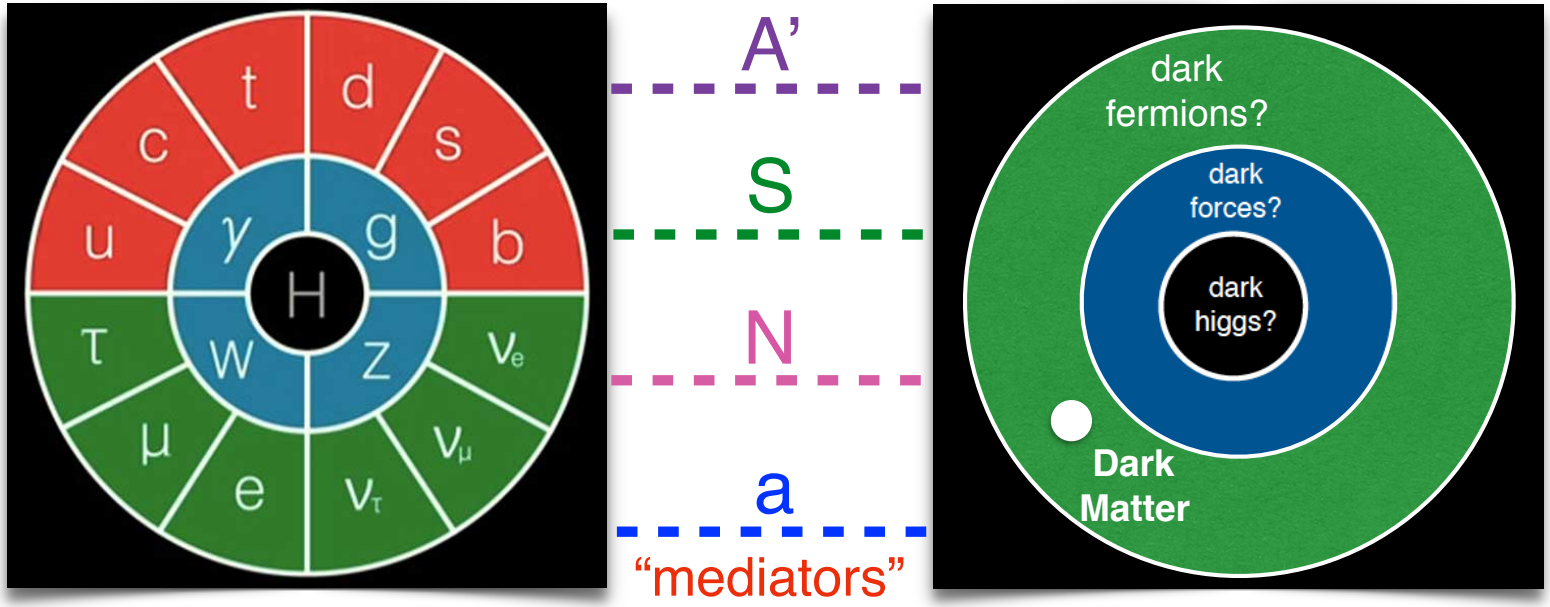

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+ possible new dark gauge bosons obtained gauging e.g. B-L, L_μ-L_τ, …

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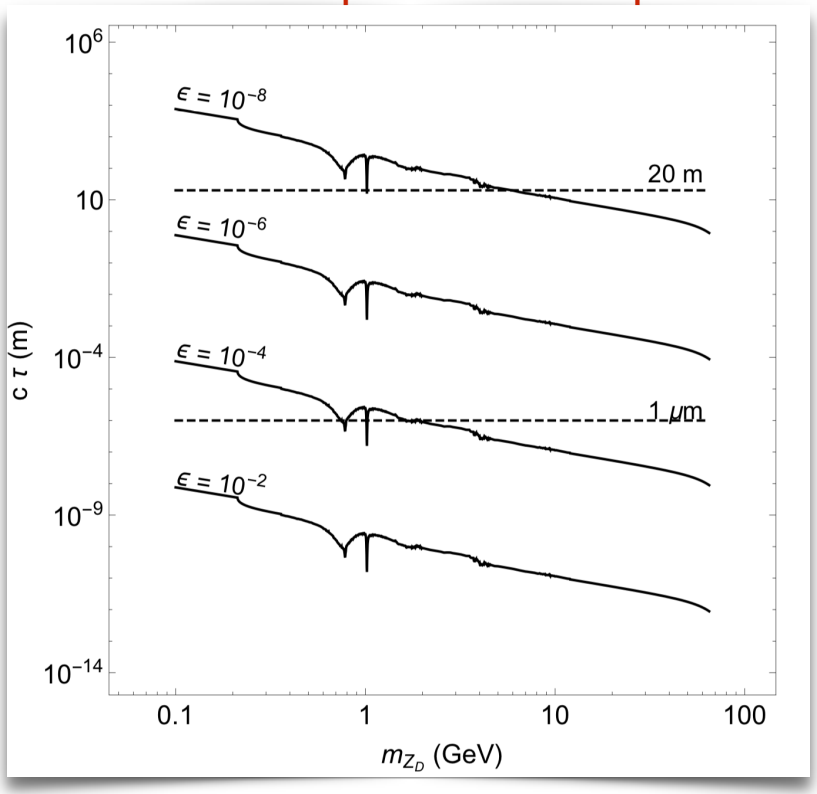
The mediator phenomenology

If the mediator is the lightest state of the dark sector:

- **it will decay back to SM particles (visible signatures)**
- Its production and life time are both connected to the same coupling (highly predictive models!)

Smaller portal coupling → { smaller production rate, longer life time

The dark photon example:



Curtin, Essig, SG, Shelton, 1412.0018

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Broad classes of models lead to this type of phenomenology:

For example:

- Secluded DM models.
  Lower bound on the mediator coupling if we require SM-dark sector thermalization;
- Models to address the strong CP problem. Axions and axion-like particles;
- Models to address the gauge hierarchy problem (relaxion);
- Models for baryogengesis;
- Models for neutrino mass generation;
- Models addressing anomalies in data ($(g\text{-}2)_\mu$, Xenon1T anomaly, B-physics anomalies, …).

2. Experimental techniques for a visible mediator

Several high-intensity experiments can be utilized to search for a visible mediator

Some experiments are large multi-purpose experiments
Some others are smaller accelerator experiments designed for dark sector physics

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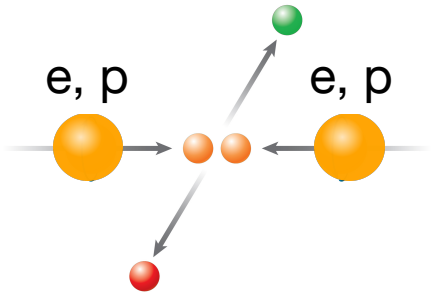
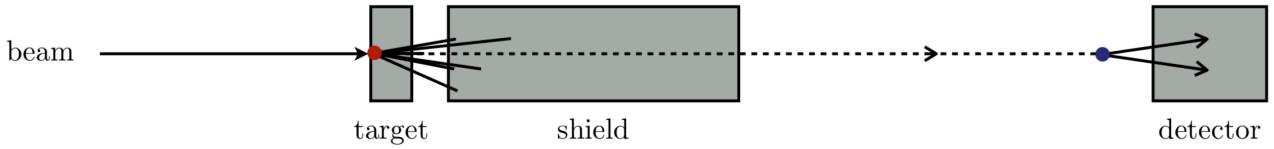
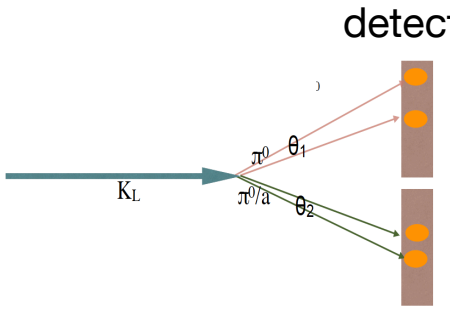
- Collider experiments (LHC(b), Belle II). *Prompt & displaced mediators*
- Fixed target beam dumps (HPS, DarkQuest, GlueX, …). *Displaced mediators*
- Light meson factories (Kaon, pion, and eta(') factories). *Prompt or displaced mediators*





Many different signatures



We have multiple LOIs for each of these sets of experiments
(several theory+exp. collaborations)

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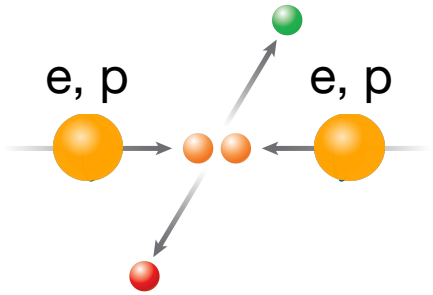

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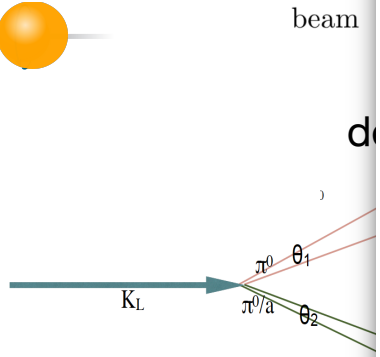

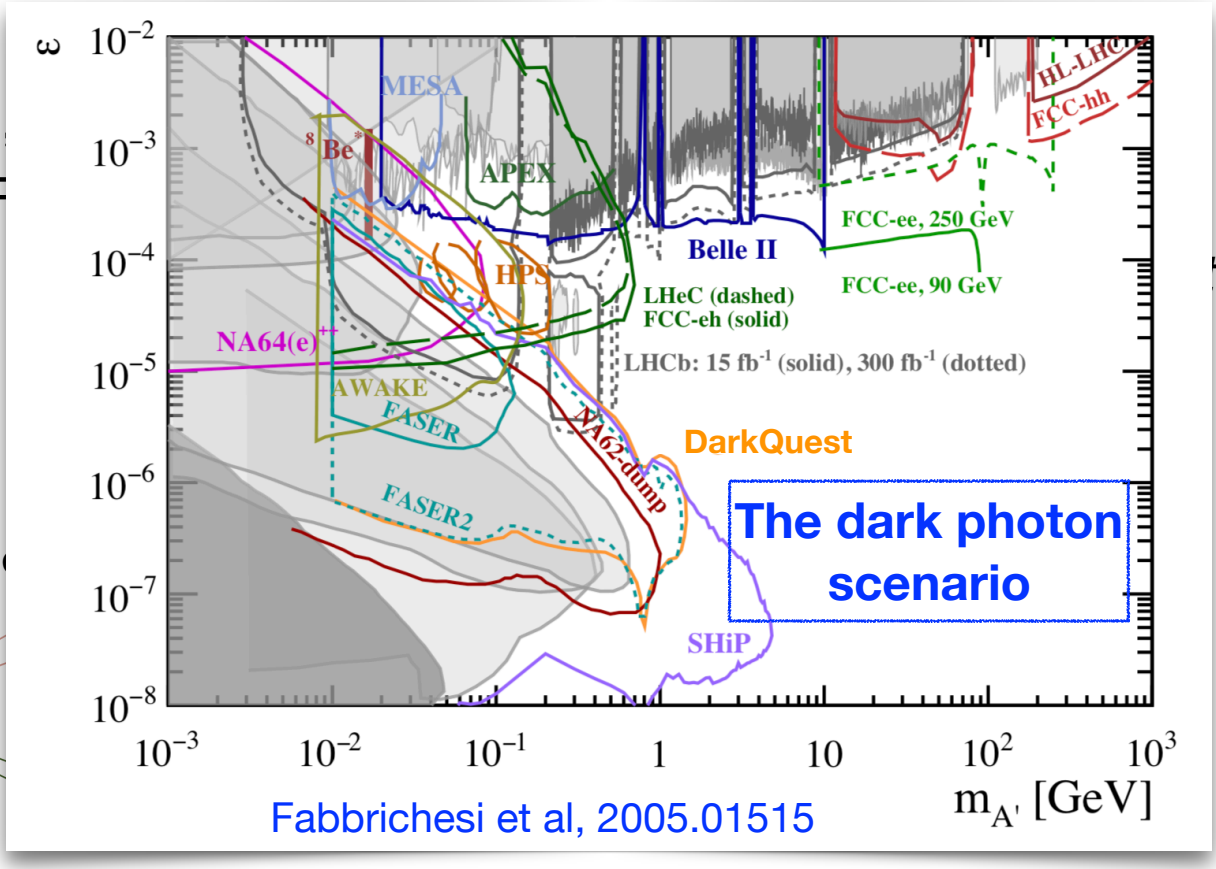

Fabbrichesi et al, 2005.01515

3. Mixed visible-invisible
"rich dark sectors"

Several Dark sector models contain particles that decay to both visible SM states and invisible states (e.g. DM)

Many examples from cosmologically motivated DM models:
Inelastic Dark Matter (IDM), Strongly Interacting Massive Particles (SIMPs), …

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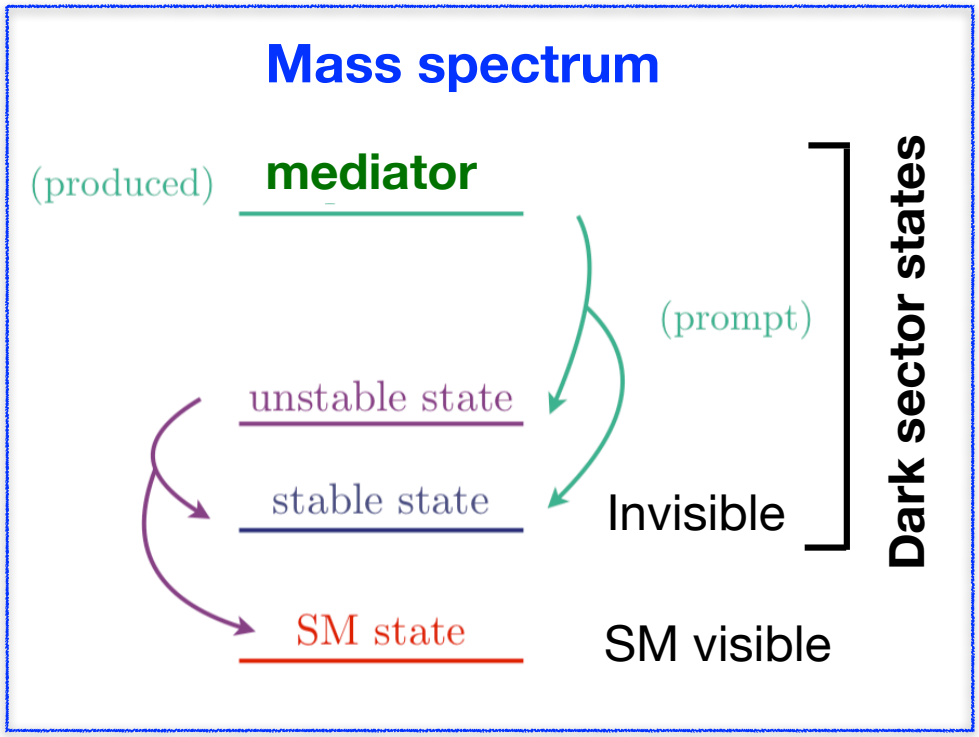
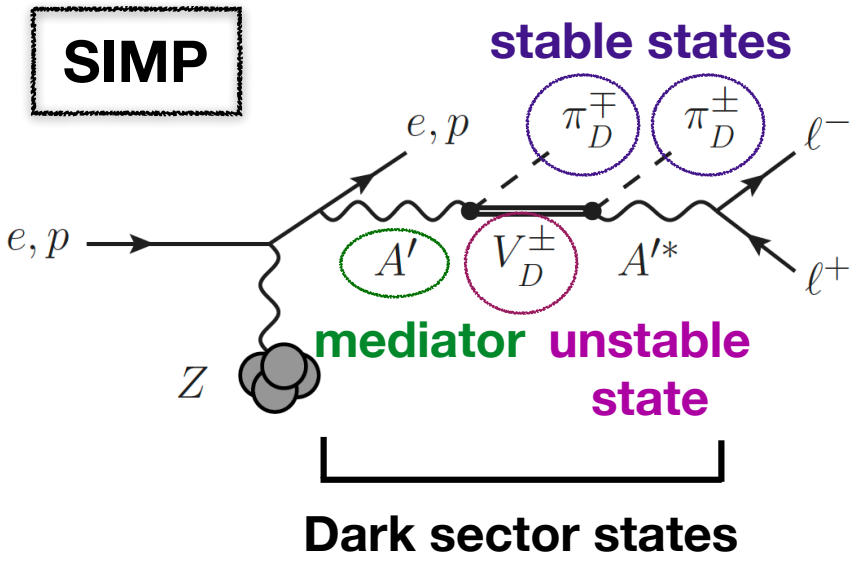


An example:



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Experimental techniques for mixed visible-invisible

- Collider experiments (LHC(b), Belle II).
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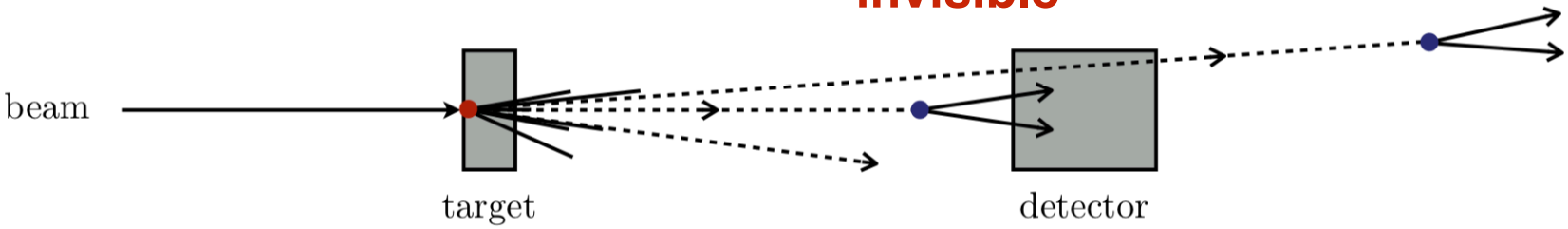
} Same techniques to discover visible mediators

- Fixed target beam dump experiments (BDX, MiniBooNE, …) looking for scattering
- Fixed target experiments (LDMX, M3, JLAB e^+, …) looking for missing momentum, missing mass, …

Focus on the "missing part"

BDX, MiniBooNE,
LDMX, M3, JLAB e^+, …
invisible



HPS, DarkQuest, GlueX, …
visible

Many new signatures need to be studied

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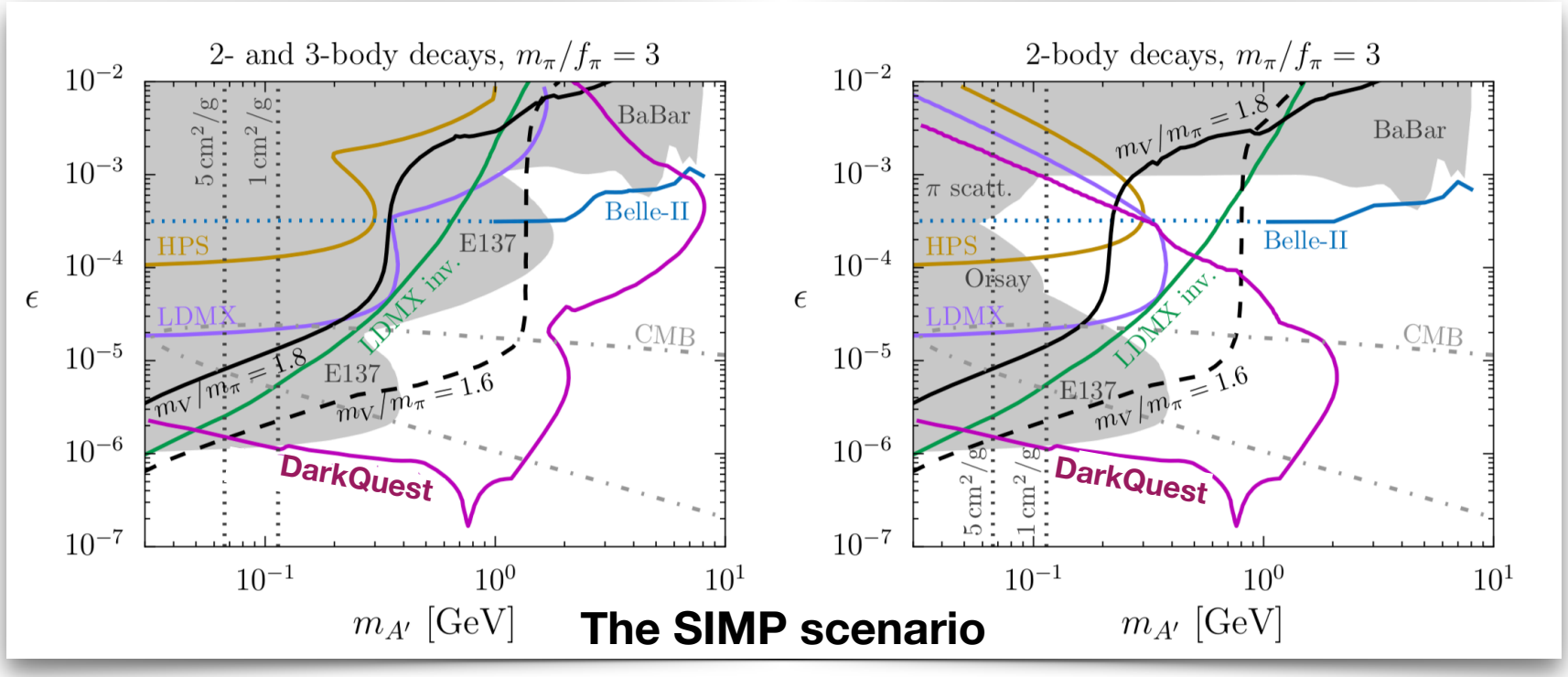
Berlin, Blinov, SG, Schuster, Toro, 1801.05805



The SIMP scenario

Conclusions & Outlook

High intensity accelerator experiments are a unique laboratory to broadly test many dark sector scenarios.

Production and detection of relativistic dark sector particles (mediator, DM, and DM excited states).

Theory development in model landscape and predictions for experiments.

Interplay of invisible, visible, and semi-visible signatures.

Complementarity of large multi-purpose experiments and smaller accelerator experiments designed for dark sector physics.

Towards a full experimental coverage of several theoretically well motivated dark sector scenarios.